

**AD-A247 694**



**RL-TR-91-340  
Final Technical Report  
December 1991**



2

# **LEAKAGE CURRENT MEASUREMENTS IN SOI DEVICES**

**Syracuse University**

**Charles Surya**

**DTIC  
ELECTE  
MAR 18 1992  
S D**

*APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.*

**92-06830**



92 3 1 111

**Rome Laboratory  
Air Force Systems Command  
Griffiss Air Force Base, NY 13441-5700**

This report has been reviewed by the Rome Laboratory Public Affairs Division (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RL-TR-91-340 has been reviewed and is approved for publication.

APPROVED:

*Nagappan K. Annamalai*  
NAGAPPAN K. ANNAMALAI  
Project Engineer

FOR THE COMMANDER:

*Harold Rott*

HAROLD ROTH, Director  
Electromagnetic & Reliability Directorate

If your address has changed or if you wish to be removed from the Rome Laboratory mailing list, or if the addressee is no longer employed by your organization, please notify Rome Laboratory (ERT) Hanscom AFB MA 01731-5000. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE December 1991		3. REPORT TYPE AND DATES COVERED Final Apr 89 - Mar 90
4. TITLE AND SUBTITLE LEAKAGE CURRENT MEASUREMENTS IN SOI DEVICES			5. FUNDING NUMBERS C - F30602-88-D-0027, Task S-9-7435 PE - 62702F PR - 4600 TA - 20 WU - P6	
6. AUTHOR(S) Charles Surya				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Syracuse University Office of Sponsored Programs Skytop Office Bldg, Skytop Rd Syracuse NY 13244-5300			8. PERFORMING ORGANIZATION REPORT NUMBER N/A	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Rome Laboratory (ERT) Hanscom AFB MA 01731-5000			10. SPONSORING/MONITORING AGENCY REPORT NUMBER RL-TR-91-340	
11. SUPPLEMENTARY NOTES Rome Laboratory Project Engineer: Nagappan K. Annamalai/ERT/(617) 377-3047				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Total dose response of both NMOS and PMOS FETs fabrication on SOI substrates were studied. Back channel leakage currents were studied. Two types of SOI substrates were chosen to study back channel leakage currents: SIMOX and ZMR. Subthreshold current-voltage characteristics as a function of total dose of the back channel and front channel of SIMOX and ZMR SOI substrates are reported. Some preliminary reports on the buried oxide leakage current are also provided.				
14. SUBJECT TERMS Bach channel leakage, SIMOX, ZMR, Total Dose Response			15. NUMBER OF PAGES 20	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

# 1 INTRODUCTION

We have studied the total dose response of both n-MOS and p-MOS FET's fabricated on SOI substrates. In particular we have performed detailed measurements on both the channel and oxide leakage currents for different levels of dosages. Two different types of SOI MOSFET's are studied: (i) SIMOX and (ii) ZMR which are fabricated by ion implantation and zone melt recrystallization respectively. The differences in the total dose response will be reported. In the next section we will describe the structure of the devices that we studied. in section three we shall outline the experiments performed and in section four we will discuss the results, in section five we shall state our conclusions based on the experimental results and in section six we will discuss the future works.

## 2 THE DEVICES

The structure of the device is shown in fig. 1, in which the device has a characteristic "H" shaped gate region. Also, there is provisions for making electrical contacts with the body. The details of the device parameters are listed in the table below:

STRUCTURE	SIMOX	ZMR
W/L ( $\mu m$ )	31.2/3.6, 1.2 7.2/1.2, H	45/3, H
Buried Oxide		
Thickness (nm)	25	36.5
Oxygen dose $cm^{-2}$	$1.4 \times 10^{18}$	NA
Anneal Time (Hrs)	4-10	NA
Si Thickness (nm)	280	300
Epi layer	Yes	- Yes

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution	
Availability Codes	
Dist. 1000000	
Dist. 1000000	
A-1	

### 3 EXPERIMENTS

The experimental set up is indicated in fig. 2. The device under test (DUT) was placed inside a shielded box for testing after being irradiated in Co-60 radiation cell building a total dose of different levels of irradiation. The time lapse between the irradiation and testing is typically about 30 minutes. The biasing conditions of the devices during irradiation is shown in the table 2 as indicated below:

TERMINAL	N-CHANNEL	P-CHANNEL
----------	-----------	-----------

$V_G$	5V	5V
$V_S$	Com	5V
$V_D$	Com	Com
$V_{G1}$	-5V	-5V
Body	NC	NC

where  $V_G$ ,  $V_S$ ,  $V_D$ ,  $V_{G1}$ , are the front gate, source, drain, and back gate biases respectively. We have measured the subthreshold I-V characteristics of both the front and back channels as a function of the total dose, and the typical results are shown in figures 3 and 4. Similar leakage current measurements were conducted with the ZMR devices and the results are shown in figures 5 and 6.

Besides measuring the leakage currents along the front and back channels of the transistors we have also studied the leakage currents through both the front and back gate oxides. In both cases the gate is biased with a dc voltage and the resulting current through the oxide is measured using the HP4140B picoammeter. The devices are housed inside a shielded box to eliminate extraneous noise since the currents are typically of the order  $10^{-12}$ A or less. Two different techniques are utilized for measuring the I-V characteristics:

1. The currents are measured at a delay of greater than 30 seconds after the gate voltages have been set. The reason for this is that transient currents with long time constants, of approximately 15sec, were observed. The transient current with respect to time immediately after a step voltage is set is shown in figure 7. The I-V characteristics

through the gate oxides with measurements made after the time delay for both top and buried oxides are shown in figures 8 and 9. The last digit of the codes for the different curves indicate the radiation dosage of the devices as indicated below

0 pre-irradiation sample

3 50 krad

4 100 krad

5 200 krad

7 750 krad

2. I-V characteristics with no time delay are shown in figures 10 - 12.

We have performed C-V measurements for different radiation dosages. The C-V measurements were typically performed at 1 MHz as shown in fig. 13. The low frequency C-V characteristics inferred from the I-V curves are shown in fig. 14

## 4 EXPERIMENTAL RESULTS AND DISCUSSIONS

From the experimental results presented in the last section it is observed that the leakage current, both along and through the gate oxides, changes with the levels of irradiation. The changes can be generally explained by the increase in the oxide charge,  $Q_{ox}$ , as well as the Si - SiO<sub>2</sub> interface states,  $D_{it}$ .

The increase in the oxide charge,  $Q_{ox}$ , is supported by the shift in the high frequency C-V curves as indicated in fig. 13. Similar conclusions can be made with the low frequency C-V curves in fig. 14. Also, the increase in the subthreshold leakage currents along the conduction channel, both are due to changes in the threshold voltage as a result in the increment in  $Q_{ox}$ . From the direction of the shift in the threshold voltages, indicated in the C-V curves as well as in the subthreshold leakage currents,  $Q_{ox}$  is found to be positively charged. However, from these measurements alone we are not able to determine whether neutral localized states are also formed within the oxide.

The long delay I-V characteristics through the oxides also supports the increase in the localized states in the oxide. We believe this leakage current is due to carriers hopping between localized states in the oxide. When the oxides are irradiated, more localized states are formed thus increasing the transition rates of the hopping process as the average distance of hops is reduced. This results in the increase in the conductance of the oxide as most clearly observed in figs. 8 and 9. However, more work is needed in order to achieve a detailed quantitative understanding of the process and to explain the bounce back phenomenon observed in some of the devices.

The increase in  $D_{it}$  can be seen from the low frequency C-V measurements in which on top of a shift in the threshold voltage changes in the shape of the C-V curves are apparent where bumps are observed. This is interpreted as the increase in surface states. This effect can also be studied by analyzing the noise characteristics and its dependence on gamma rays irradiation.

## 5 CONCLUSIONS

We have shown that gamma rays irradiation causes an increase in both the oxide charges and interface states. This results in an observed shift in the threshold voltage leading to an increase in the subthreshold leakage current parallel to the gate area. However, another type of leakage current that conducts through the oxide suggests an increase in the density of localized states in the oxide with gamma rays irradiation. These states can be neutral or charged, for this reason the threshold voltage shifts and subthreshold leakage alone are not able to completely characterize the effects of gamma irradiation.

## 6 REMARKS ON FUTURE WORK

More work is needed to characterize the leakage current through the oxide. This includes an fundamental understanding of the mechanisms of the leakage current. Specifically, by measuring the variation of the conductance of the oxide film with temperature as well as radiation dosage we will be able to confirm whether a hopping mechanism is involved. These measurements will also enable us to measure the activation energies involved and the mean

distance of the hops. These information are valuable in the understanding of the total effects radiation on the quality of the oxide films as well as a quantitative measure of the increase in the localized states within the gate oxides. We also suggest a study of the dependance of the device noise with radiation dosages. This is particularly important for analog applications, also it has long been known that low frequency excess noise is a powerful technique for characterizing the density of interface states at the Si - SiO<sub>2</sub> interface particularly at the energy ranges outside the capability of traditional C-V measurements.



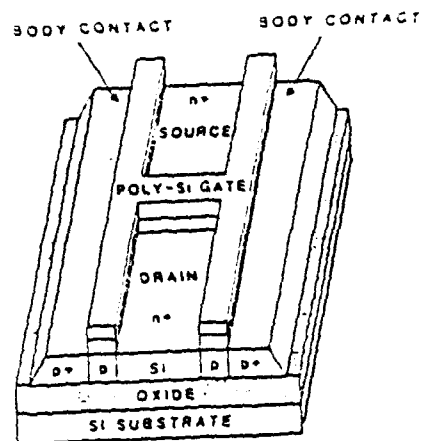


Fig. 1. A MOSFET structure with body contact on SOI substrate.

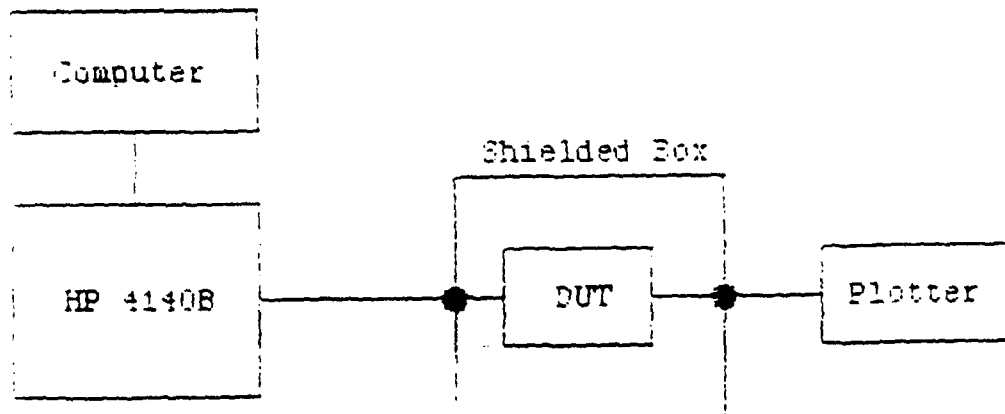


fig. 2

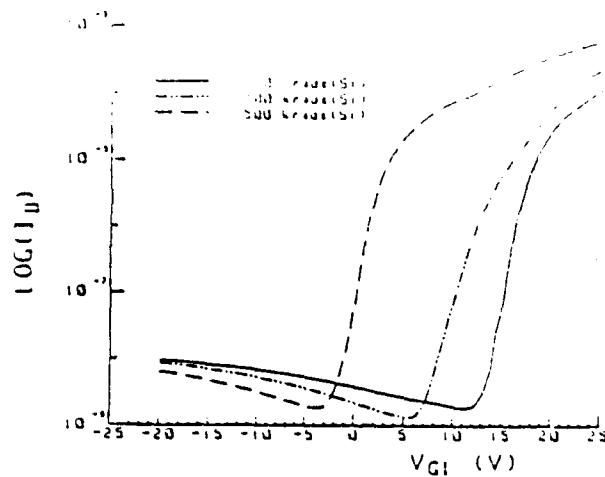


Fig. 3 Subthreshold  $I_D$ - $V_{G1}$  characteristics of the back channel of a 1.2  $\mu\text{m}$  SIMOX NMOS with  $V_{G1} = -5$  V and  $V_D = 5$  V as a function of total dose.

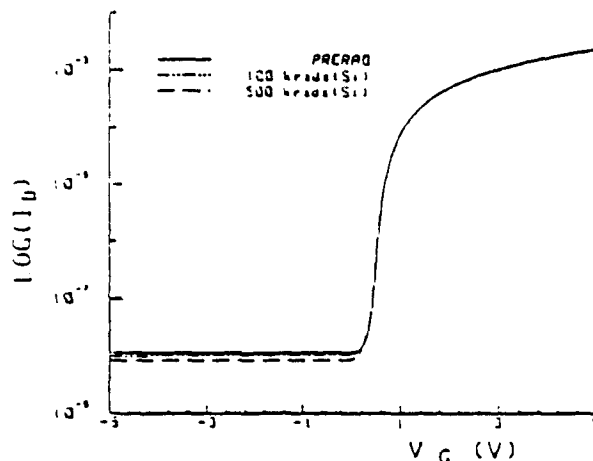


Fig. 4 Subthreshold  $I_D$ - $V_G$  characteristics of the front channel of a 1.2  $\mu\text{m}$  SIMOX NMOS with  $V_{G1} = -20$  V and  $V_D = 5$  V as a function of total dose.

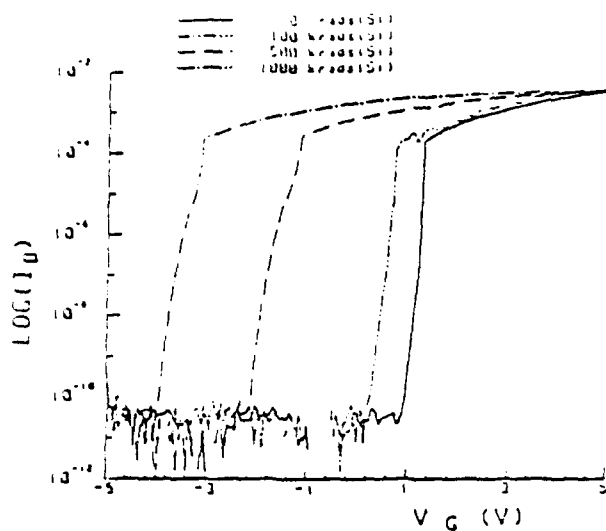


Fig. 5 Subthreshold  $I_D$ - $V_G$  characteristics of the front channel of a 3  $\mu$ m ZMR NMOS with  $V_{G1} = -20$  V and  $V_D = 3$  V as a function of total dose.

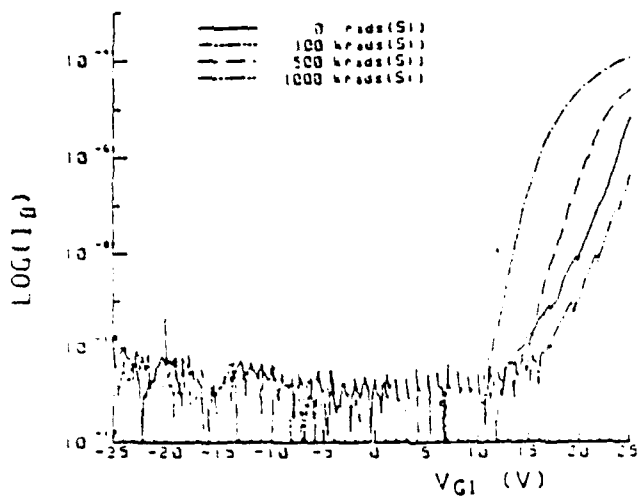
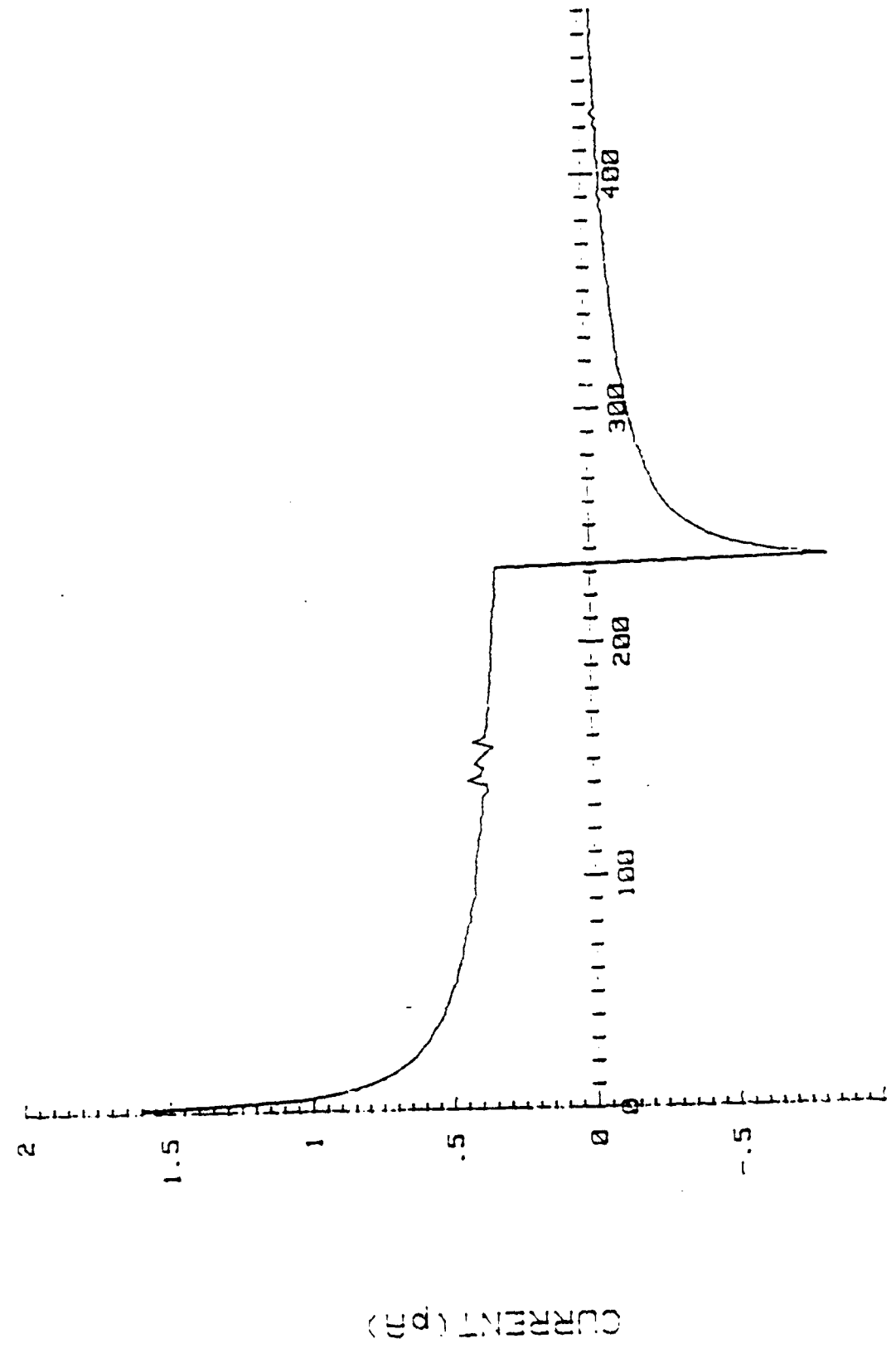


Fig. 6 Subthreshold  $I_D$ - $V_{G1}$  characteristics of the back channel of a 3  $\mu$ m ZMR NMOS with  $V_{G1} = -20$  V and  $V_D = 3$  V as a function of total dose.

CURRENT

TRANSIENT

5013D1



TIME(S)

fig. 7

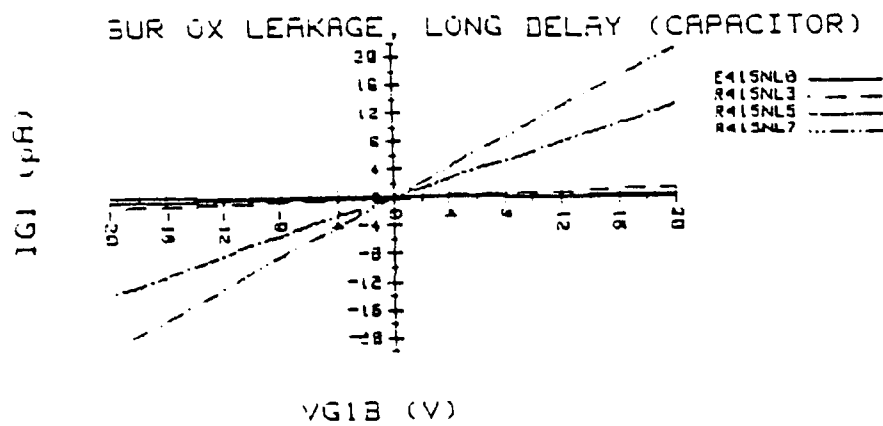


fig. 8

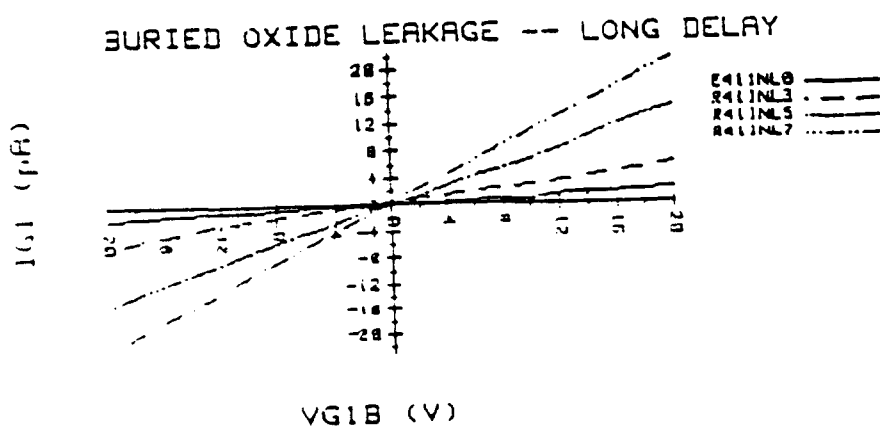
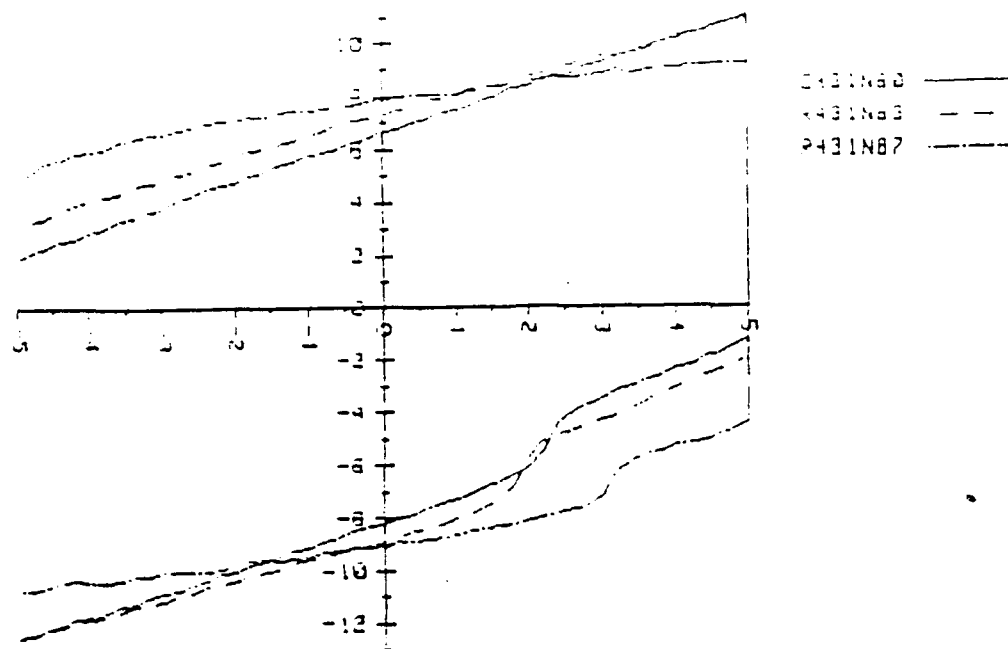


fig. 9

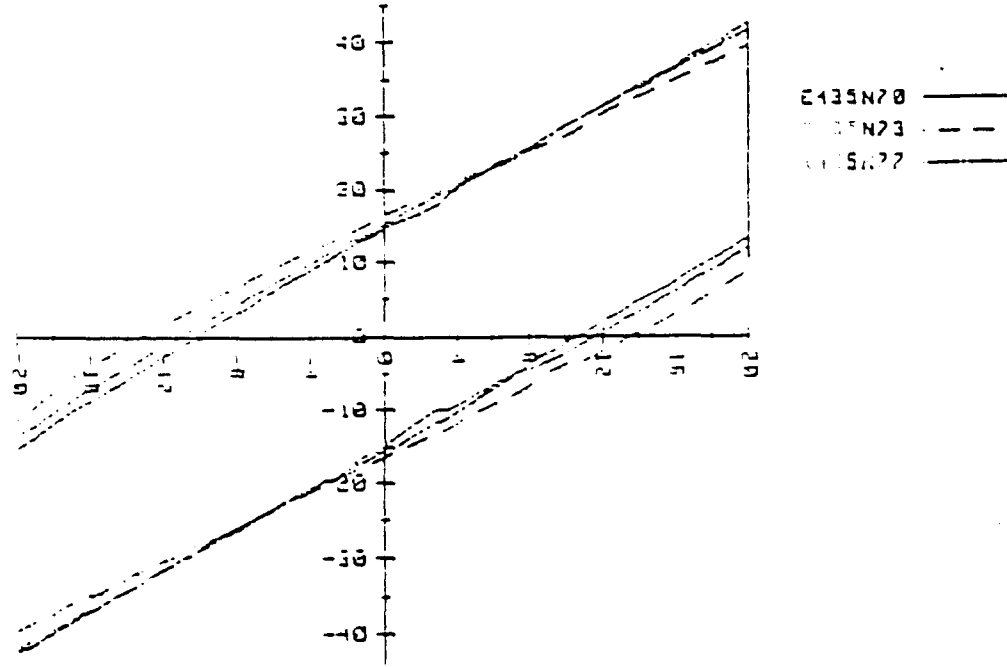
# TOP GATE OXIDE CURRENT --



$V_{GB}$  (V)

Fig. 10

## BURIED OXIDE CURRENT



$V_{GB}$  (V)

Fig. 11

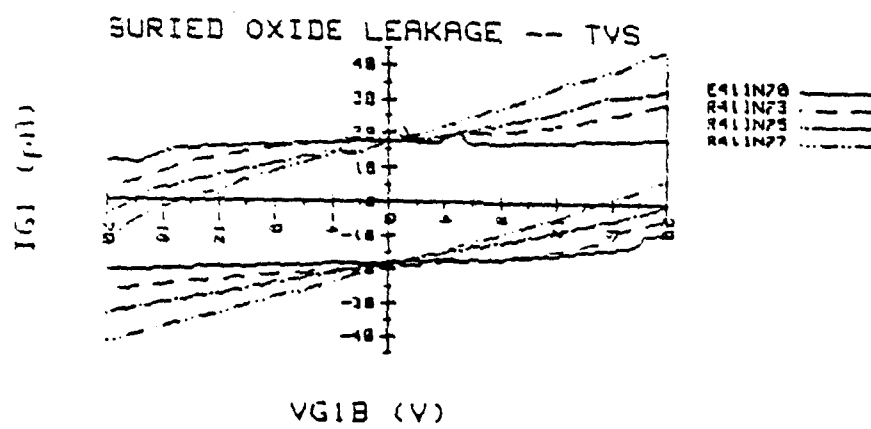


fig. 12

# BURIED INIDE TIME CAPACITANCE

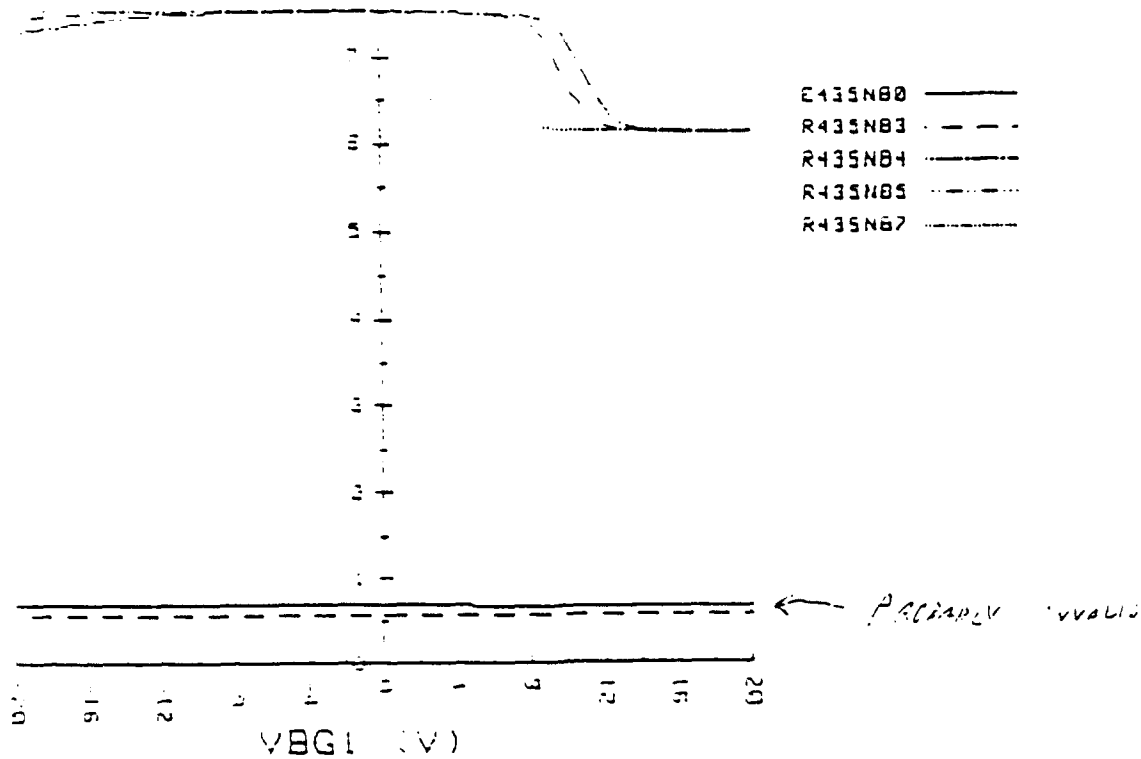


fig. 13

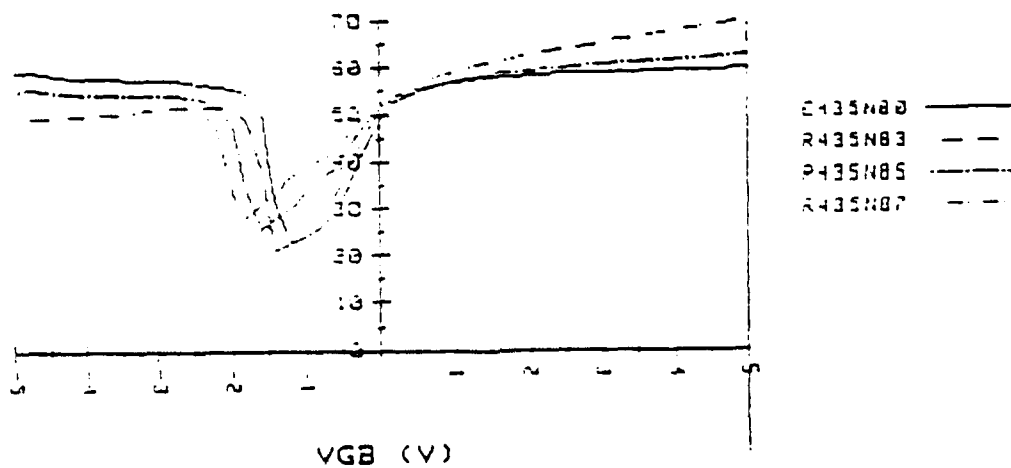


fig. 14



**MISSION  
OF  
ROME LABORATORY**

*Rome Laboratory plans and executes an interdisciplinary program in research, development, test, and technology transition in support of Air Force Command, Control, Communications and Intelligence (C<sup>3</sup>I) activities for all Air Force platforms. It also executes selected acquisition programs in several areas of expertise. Technical and engineering support within areas of competence is provided to ESD Program Offices (POs) and other ESD elements to perform effective acquisition of C<sup>3</sup>I systems. In addition, Rome Laboratory's technology supports other AFSC Product Divisions, the Air Force user community, and other DOD and non-DOD agencies. Rome Laboratory maintains technical competence and research programs in areas including, but not limited to, communications, command and control, battle management, intelligence information processing, computational sciences and software producibility, wide area surveillance/sensors, signal processing, solid state sciences, photonics, electromagnetic technology, superconductivity, and electronic reliability/maintainability and testability.*